ELECTRON INTERACTION WITH A MAGNETIC FIELD

(L-24)

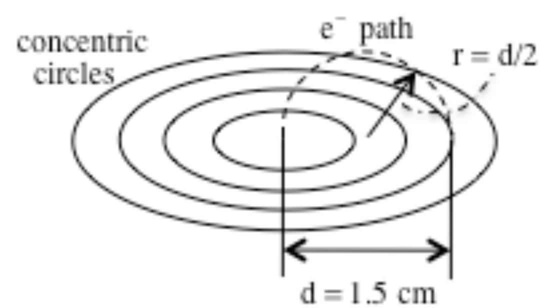
When electrons are made to move in a vertical beam through a horizontal magnetic field, a centripetal force acts upon the electrons due to the interaction of their motion and the ***B**-field*. Knowledge of this phenomenon will allow us to experimentally determine the mass m of an electron.

PROCEDURE--DATA

Part A: (the setup)

a.) The device is shown on the next page. It is there for two reasons. First, it is there so you will know what you are about to play with. Second, it is there so the following discussion will make sense. Look at the sketch now.

b.) Design: A beam of electrons is provided by a vacuum tube that works as follows: Electrons are excited off a cathode plate and accelerated through a known, *power supply provided* electrical potential difference of V volts to an anode plate. The anode is disk-shaped with a pin hole at its center. As the accelerated electrons reach the anode, they pass through the hole and into the upper part of the tube. Once in this region, the electrons collide with an inert gas producing a stream of ionizations and, hence, a blue beam of light. This beam is what will allow you to track the electrons as they pass through the tube.



Under normal circumstances (i.e., with no external forces acting save gravity), the beam will travel in a straight, vertical line. But when a horizontal magnetic field is applied, the beam will respond by moving into a semi-circular path the radius of which will depend upon the electron's *charge* and *speed* and on the *magnitude of the magnetic field* (gravity ignored). The magnitude of such a force is easily calculable. Furthermore, we can use N.S.L. and the fact that the electron's acceleration is centripetal to derive a general algebraic expression for the mass *m* of the electron in terms of the magnitude of the magnetic field *B*, the electron's charge *q*, the electron's velocity *v*, and the electron's radius of curvature *r*.

c.) The math involved is not simple, but it is doable. What you are about to read is a summary. The actual math required for the write-up is alluded to in the Calculations section.

i.) Within the vacuum tube, electrons are boiled off a cathode terminal and accelerated via an electric field toward an anode. Using *conservation of energy*, and remembering that the potential energy of an electron located at a point where the electrical potential is *V* volts, we can write

$$\sum KE_1 + \sum U_1 + \sum KE_1 = \sum KE_2 + \sum U_2$$
$$0 + 0 + 0 = (1/2)mv^2 + (-qV)$$
$$\Rightarrow v = \left(\frac{2qV}{m}\right)^{1/2}.$$

Note that there are two "v" terms in the expression. The term "v" is the electron velocity. The "V" term is the voltage that accelerated the electrons.

ii.) The magnetic field inside a Helmholtz coil that has *i's* worth of current passing through it is given by the relationship $B = \frac{8\mu_o Ni}{R(125)^{1/2}}$, where *R* is the radius of the Helmholtz coil (you need to measure this), *N* is the number of loops in the Helmholtz coil (this should be printed on the device), *i* is the current through the coils, and μ_o is a constant equal to 1.26×10^{-6} H·m

ii.) The magnetic force on moving charge is equal to *qvB*, where *q* is the charge of an electron (i.e., 1.6×10^{-19} coulombs), *v* is the velocity of each electron, and *B* is the magnetic field intensity.

iii.) The fact that magnetic forces are centripetal yields a Newton's Second Law expression of from which we can solve for the mass *m* of an electron. That is:

$$\sum F:$$

$$qvB = ma_c$$

$$qvB = m\left(\frac{v^2}{r}\right)$$

$$\Rightarrow \quad m = \frac{qBr}{v},$$

iv.) Plugging in the magnetic field function allows us to solve for the mass. I'd do it for you, but I wouldn't want to take all the fun out of the lab.

Part B: (the setup and data taking)

d.) The circuit is shown on the next page. It has been included in deference to whoever sets the apparatus up. If you are lucky, all the work will be done by the time you get to lab.

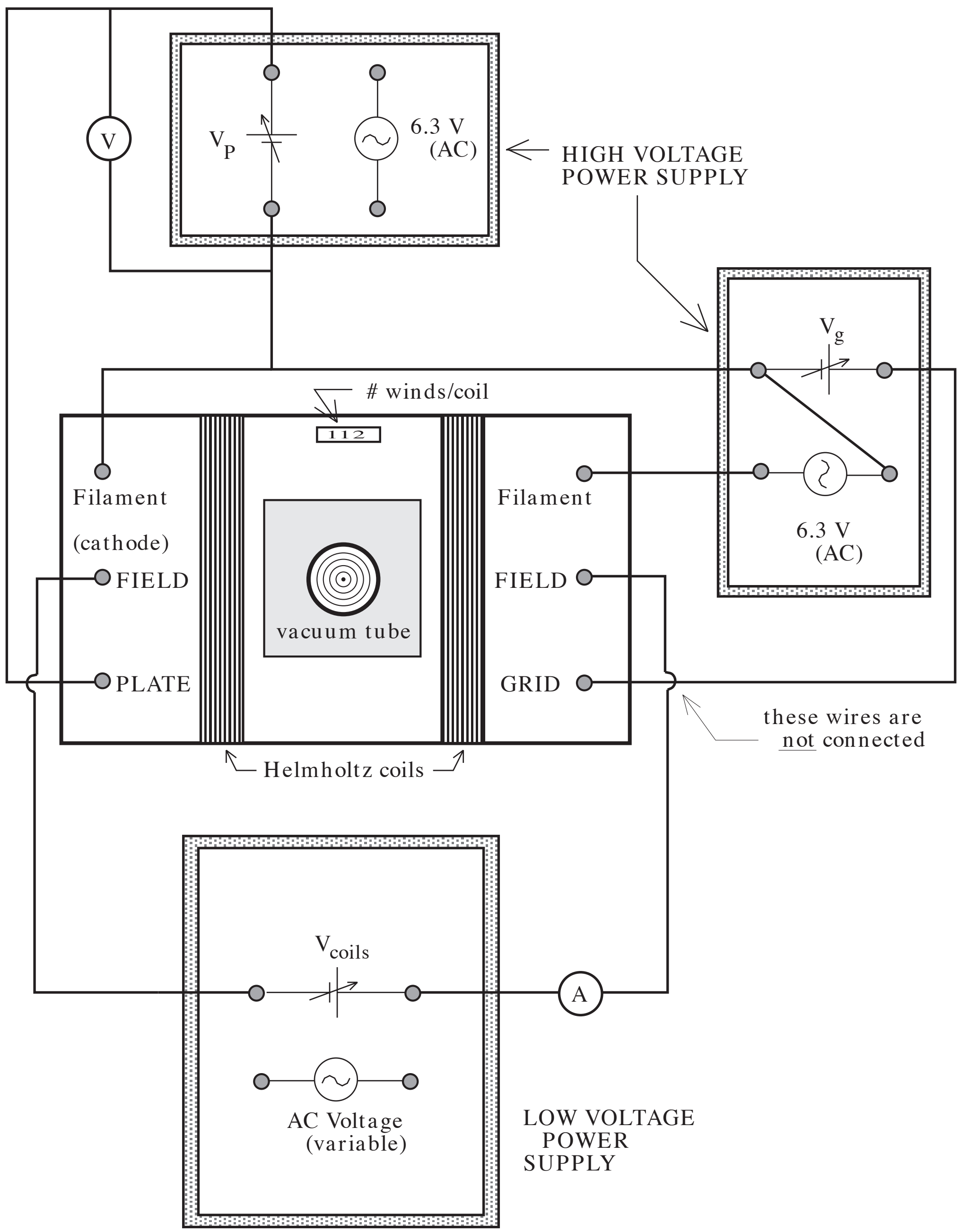
e.) As for data taking, you will need the following bits of information:

i.) The number of winds in the Helmholtz coil (this should be printed on the device).

ii.) The radius *R* of the Helmholtz coil.

iii.) The "plate voltage" that accelerates the electrons.

iv.) The current required to make the beam bend into an arc of radius .01 meter. (The fluorescent circles on the tube's plate will help you with this when the time comes.)



V
V_P
6.3 V
(AC)
HIGH VOLTAGE
POWER SUPPLY
V_g
winds/coil
112
Filament
(cathode)
Filament
6.3 V
(AC)
FIELD
FIELD
vacuum tube
PLATE
GRID
these wires are
not connected
Helmholtz coils
V_coils
A
AC Voltage
(variable)
LOW VOLTAGE
POWER
SUPPLY

CALCULATIONS

1.) Using the relationships provided in the preamble (i.e., $v = \left(\frac{2qV}{m}\right)^{1/2}$ and $m = \frac{qBr}{v}$), derive a general algebraic expression for the mass *m* of the electron. Note that you can't have *m* terms on both sides of the equal sign, and note also that this will be in terms of the electron charge *q*, the plate voltage *V*, the magnetic field *B*, and the beam's arc-radius *r*. If you have trouble with the algebra, COME SEE ME!

2.) Using the magnetic field relationship provided in the preamble (i.e., $B = \frac{8\mu_o Ni}{R(125)^{1/2}}$,), determine the magnitude of the magnetic field required to make the beam of electrons flow into an arc of radius .01 meters.

3.) Using the relationships derived in *Calculation 1* in conjunction with the magnetic field value determined in *Calculation 2*, determine the mass of the electron from your data when the beam's arc radius is .01 meters.

4.) The accepted value for the mass of an electron is $9.1\text{x}10^{-31}$ kilograms. Showing your work, do a % comparison between the value you determined above and the actual value. Comment on any discrepancy.